CHAPTER 11

MODIS
Geometric Calibration

Objectives

Characterize the MODIS Instrument Geometry - Computing the instrument line of sight at all scan angles and determining sub-pixel band and detector offsets

Develop and Implement the MODIS Geolocation Algorithm - Objective is to meet the Science Team Accuracy requirements

Develop contingency plans for compensating for degraded spacecraft/instrument pointing knowledge

Monitor MODIS data product geolocation accuracy post-launch and refine the pre-launch knowledge of the instrument geometry (internal and external)

Methods

Documents Related to MODIS Geometric Characterization and Calibration:

- MODIS Geolocation Algorithm Theoretical Basis Document (ATBD)
- MODIS Earth Location Prototype and Test Plan
- MODIS Earth Location Error Report

Pre-launch Instrument Geometric Characterization

Laboratory Calibration and Characterization of the Instrument; Instrument Builder (SBRC) Responsibility

Measurement of the Instrument to Spacecraft Alignment During Payload Integration; Spacecraft Builder (Martin Marretta) Responsibility

Support Analysis of Pre-flight data; MCST and SDST Responsibility; Effect of Spacecraft and Instrument Performance on Geolocation performed by SDST and Documented in the Earth Location Error Report

Pre-launch Geolocation Prototyping

- Detailed Description of Plan and Schedule presented in MODIS Earth Location Prototyping and Test Plan
- Activity will Validate Level 1A Geolocation Algorithm
- Develop techniques and software tools for control point quality assurance (QA), data analysis and geometric parameter estimation
- Includes assembly of Prototype Control Point Library for Geometric Accuracy Assessment
- Control Point Correlation and Sub-pixel Mensuration Techniques

Pre-launch Operational Software Development

Automated Ground Control Correlation as QA Step

Used for Assembling a Record of Geolocation Performance for Off-line Analysis

Global Library of Control Point Images will be Assembled from Higher Resolution (e.g. TM or MSS) Image Data or Accurate Digital Cartographic Shoreline Data

Global Distribution and Type of Control Determined by:

- Prototyping - Relative Accuracy of the Methods
- Anticipated Knowledge Error Budgets (both Static and Dynamic Spacecraft and Instrument)
- Cost - Labor and Data

Operational versions of Prototype Geolocation Error Analysis Tools will be Developed for Use in the Team Leader Science Computing Facility (TCLF)

Post-launch Level 1A Geolocation Processing

Automated Geolocation Accuracy Assessment Using Ground Control

A Subset (at least) of the Level 1A Products Assess on a Continuous Operational Basis

250 Meter Visible band in Cloud Free Areas Used to Measure Residual Distortion

Sub-pixel Mensuration Techniques will be Developed During Prototype Phase

Manual Control Point Mensuration will be Used to Validate Performance of the Automated Process Immediately after Launch

Off-line Analysis done at TLCF

Use of SRCA

Reticule Pattern Used to Measure Band and Detector Alignment

MCST Will Use the SRCA to Monitor Spatial Stability and Provide Updated Detector Field Angles

Geolocation Algorithm Computes Locations Only at 10 Ideal Spatial Element Locations (1 km) - Sub-pixel Corrections are Needed to Relate Locations of Real Detectors to their Ideal Counterparts

Initial Post-launch Along Scan Focal Plane Registration Provided by MCST

Accuracy Analysis and Parameter Estimation

Post-processing and Analysis Tasks will be Performed on the TLCF using the Control Point QA Data Collected

Initially a Summary of the QA data from Multiple Products will be Used to Document the Geolocation Algorithm Performance and Level 1A Product Accuracy

Provides a Quantifiable Basis for Developing and Documenting Requirements for Improved Geolocation Accuracy if Needed

Orbital Passes with Many Visible Control Points will be Used to Characterize Temporal Behavior of Residual Geolocation Errors

Accuracy Analysis and Parameter Estimation (con't)

Nature, Magnitude and Dynamic Behavior of Residual Geolocation Error Needed in Order to Evaluate the Feasibility of Using On-line Control Point Processing to Improve Geometric Accuracy

Corrections for Rapidly Varying Dynamic Errors Can Not be Estimate Using Ground Control Points on an Operational Basis

Accuracy Analysis and Parameter Estimation - Residual Geolocation Error

- Control Point QA Results will be Used to Detect Trends in the Residual Geolocation Error Based on a Time Series of Products
- Pre-launch Knowledge of Instrument to Spacecraft Alignment will be Refined
- With-in Scan Trends will be Used to Investigate Refinements to the Mirror Model
- QA Results May be Used to Detect and Develop Models for Repeatable Within-Orbit Variations (e.g. Thermal Effects)

Accuracy Analysis and Parameter Estimation - Ancillary Data Quality

Geolocation Accuracy Assessment and Analysis Tools Can be Used to Evaluate the Quality of Ancillary Data Used to Generate the Level 1A Geolocation Data

Estimate the Accuracy of Position and Attitude Data - Image Data from MISR and ASTER can be Used In Conjunction with MODIS Image data; Multi-team Effort with Participation of the Flight Dynamics Facility

Digital Terrain Model Data Quality - Tie Points from Multiple Passes Can be Used to Identify and Document Regions of Poor Quality Digital Elevation Data

Expected Geolocation Performance

MODIS Geolocation Accuracy Goal is 0.1 Pixel

Three cases discussed in "An Analysis of MODIS Earth Location Error"

1. Geolocation accuracy if spacecraft and instrument specifications are met
2. Geolocation accuracy if spacecraft and instrument meet current performance estimates
3. Geolocation accuracy given current performance estimates after removal of static bias terms

Geolocation Impact of 2 sigma Spacecraft Position Errors

Spacecraft Position	**X-Axis** Platform Position Error	Corresponding **Along-Track** Earth Location Error		**Y-Axis** Platform Position Error	Corresponding **Cross-Track** Earth Location Error		**Z-Axis** Platform Position Error	Corresponding **Cross-Track** Earth Location Error	
		scan = 0	scan = 55		scan = 0	scan = 55		scan = 0	scan = 55
Current Spec	100.0 m	90.0 meters or .090 pixels*	88.5 meters or .044 pixels*	100.0 m	90.0 meters or .090 pixels*	90.0 meters or .019 pixels*	100.0 m	0.0 meters	197.3 meters or .041 pixels*
Likely-Built	44.3 m	39.0 meters or .039 pixels*	38.4 meters or .019 pixels*	24.0 m	21.6 meters or .022 pixels*	21.6 meters or .004 pixels*	6.7 m	0.0 meters	13.2 meters or .003 pixels*
Likely-Built bias removed	44.3 m	39.0 meters or .039 pixels*	38.4 meters or .019 pixels*	24.0 m	21.6 meters or .022 pixels*	21.6 meters or .004 pixels*	6.7 m	0.0 meters	13.2 meters or .003 pixels*

* using a 1-km resolution pixel

Error Budget - Geolocation Impact of 2 sigma EOS AM Platform Attitude Knowledge Error Components

Platform Attitude	**Roll** Pointing Error	Corresponding **Cross-Track** Earth Location Error			**Pitch** Pointing Error	Corresponding **Along-Track** Earth Location Error			**Yaw** Pointing Error	Corresponding **Along-Track** Earth Location Error	
		scan = 0	scan = 55			scan = 0	scan = 55			scan = 0	scan = 55
Current Spec	60.0 arcsecs	205.1 meters or .205 pixels*	990.5 meters or .205 pixels*		60.0 arcsecs	205.1 meters or .205 pixels*	235.9 meters or .118 pixels*		60.0 arcsecs	0.0 meters	336.9 meters or .168 pixels*
Likely Built	36.7 arcsecs	125.3 meters or .125 pixels*	605.3 meters or .125 pixels*		51.5 arcsecs	175.9 meters or .176 pixels*	202.4 meters or .101 pixels*		32.3 arcsecs	0.0 meters	181.2 meters or .090 pixels*
Likely Built bias removed	7.3 arcsecs	25.1 meters or .025 pixels*	121.1 meters or .025 pixels*		9.3 arcsecs	31.9 meters or .032 pixels*	36.7 meters or .018 pixels*		6.1 arcsecs	0.0 meters	34.1 meters or .017 pixels*

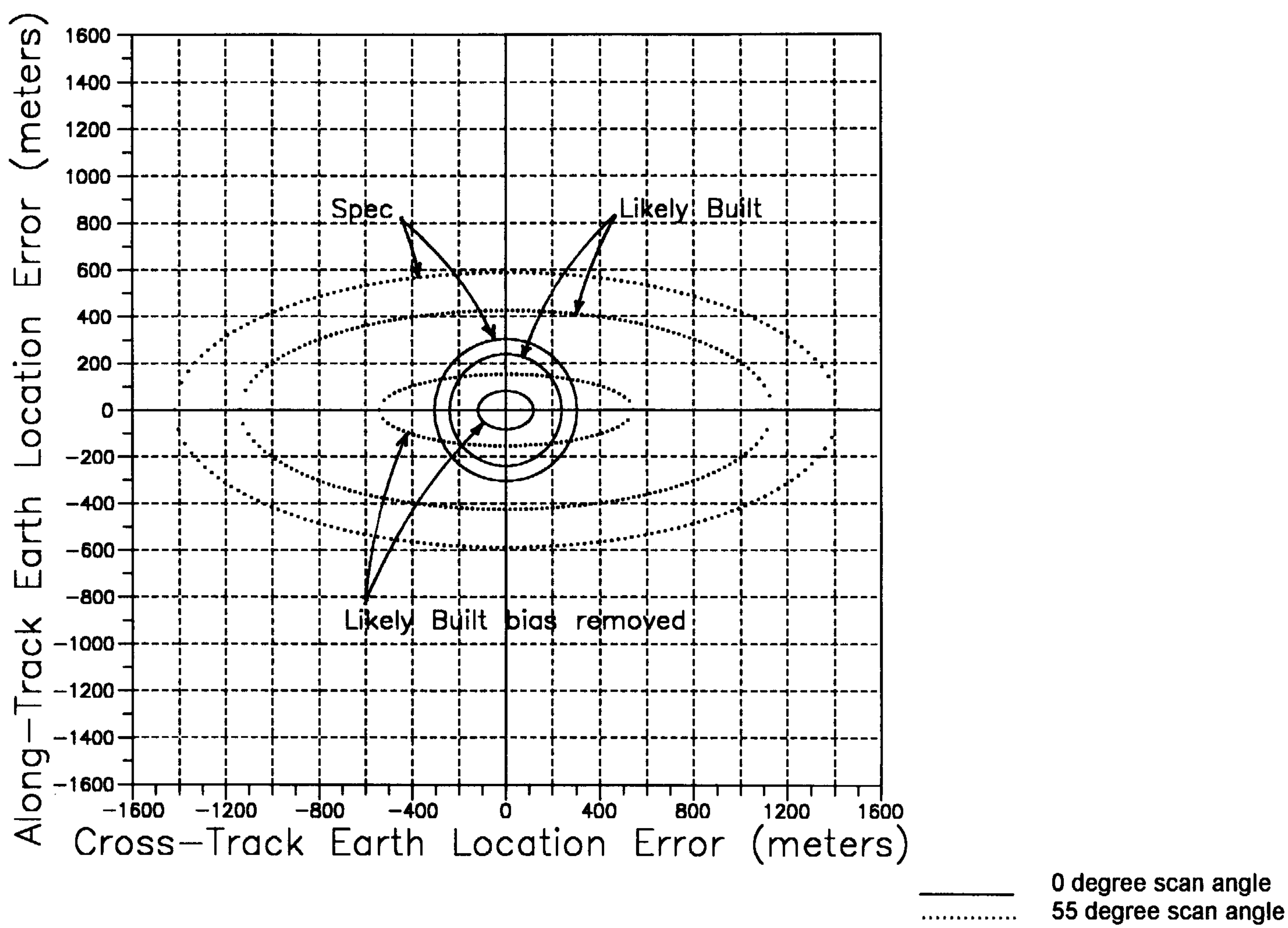
* using a 1-km resolution pixel

Error Budget - Geolocation Impact of 2 sigma MODIS Instrument Pointing Knowledge Error Components

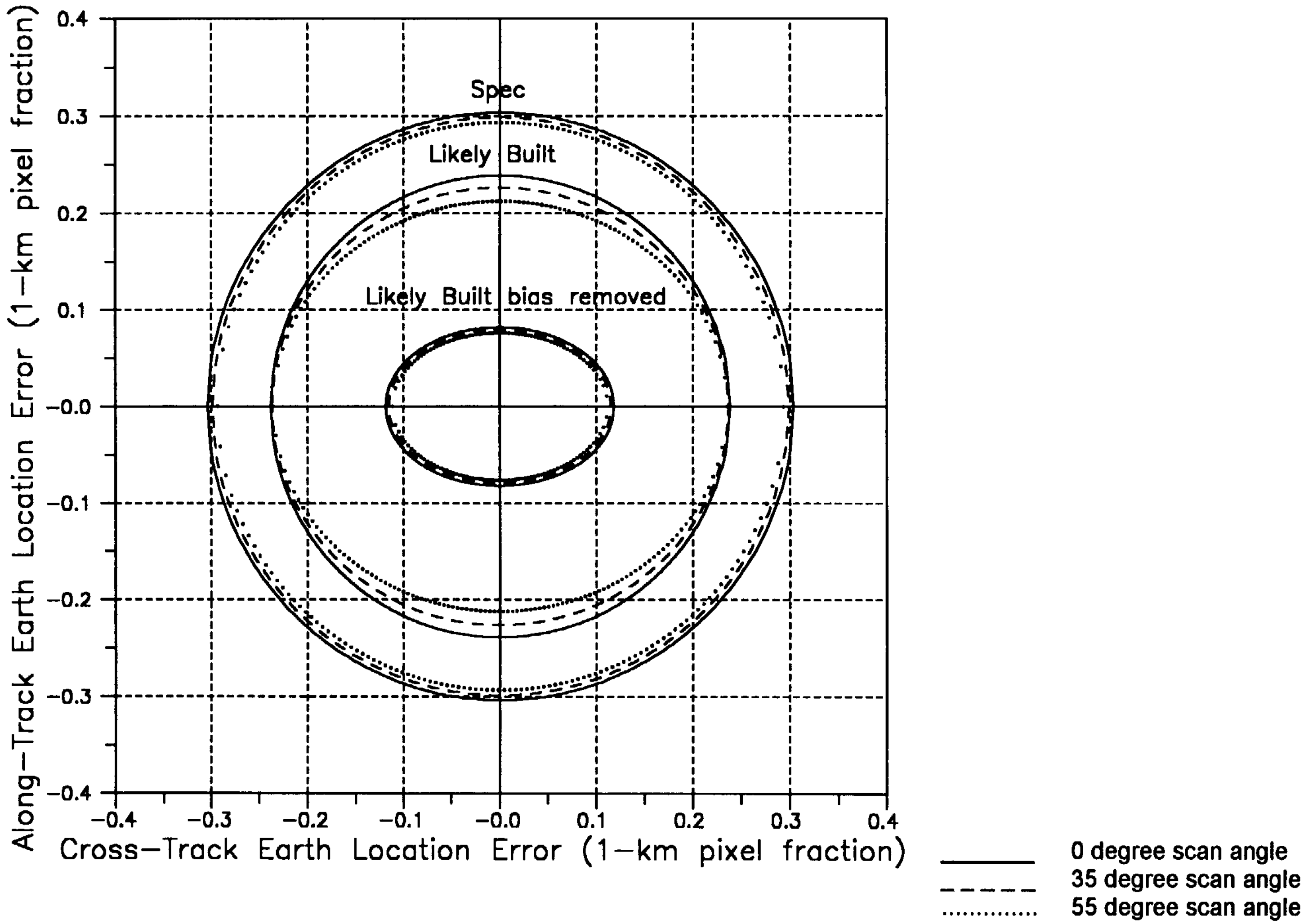
Instrument Pointing	**Roll** Pointing Error	Corresponding **Cross-Track** Earth Location Error		**Pitch** Pointing Error	Corresponding **Along-Track** Earth Location Error		**Yaw** Pointing Error	Corresponding **Along-Track** Earth Location Error	
		scan = 0	scan = 55		scan = 0	scan = 55		scan = 0	scan = 55
Current Spec	60.0 arcsecs	205.1 meters or .205 pixels*	990.5 meters or .205 pixels*	60.0 arcsecs	205.1 meters or .205 pixels*	235.9 meters or .118 pixels*	60.0 arcsecs	0.0 meters	336.9 meters or .168 pixels*
Likely Built	57.1 arcsecs	195.3 meters or .195 pixels*	943.2 meters or .195 pixels*	44.0 arcsecs	150.4 meters or .150 pixels*	173.0 meters or .086 pixels*	46.9 arcsecs	0.0 meters	263.6 meters or .131 pixels*
Likely Built bias removed	30.4 arcsecs	103.9 meters or .104 pixels*	501.9 meters or .104 pixels*	17.3 arcsecs	59.0 meters or .059 pixels*	67.9 meters or .034 pixels*	20.7 arcsecs	0.0 meters	116.1 meters or .058 pixels*

* using a 1-km resolution pixel

Geolocation Error in Meters (2 sigma)



Geolocation Error in Pixels (2 sigma)



Geolocation Performance Summary

Specification implies 0.3 pixel (2 sigma) accuracy

Likely built performance estimates imply 0.25 pixel (2 sigma) accuracy available at launch

- Includes large static error component

Use post-launch static bias estimation and removal to approach 0.1 pixel (2 sigma) accuracy over time

Pre-launch Activities

1. Design data structure for MODIS Earth location data
2. Develop ingest and preprocessing software to convert AVHRR LAC 1B data to simulated MODIS scan geometry
3. Develop prototype software for Earth location using an ellipsoidal Earth model
4. Develop prototype terrain data preprocessing software
5. Develop prototype terrain correction algorithm
6. Collect prototype control point data
7. Develop prototype control point correlation techniques and software
8. Develop prototype forward (pixel to ground) and inverse (ground to pixel) parametric geolocation algorithm and software
9. Develop geometric parameter estimation techniques and software
10. Develop prototype image-to-image tie point mensuration and orbit-to-orbit adjustment techniques and software

Post-launch Schedule

Time Frame	Activity
Short Term (first three months)	Validate geolocation algorithm performance as soon as operational data becomes available using manual control point mensuration.
	Look for constant bias terms in control point QA results to assess accuracy of instrument alignment knowledge.
	Analyze early SRCA reticle data to verify post-launch band and detector alignment.
Medium Term (first year)	Estimate refinements to instrument alignment knowledge using control point QA data.
	Analyze ancillary digital terrain data accuracy using orbit-to-orbit tie points.
	Analyze control point QA results to characterize repeatable errors correlated with scan angle and/or mirror side.
	Use control point QA results to detect repeatable within-orbit trends such as thermal effects.
	Use data from multiple instruments to estimate spacecraft position and attitude accuracy performance.
Long Term (sustaining activities)	Analyze control point QA data for trends to monitor stability of instrument geometric parameters.
	Refine geometric models for mirror and thermal effects as appropriate based on longer data record.

Validation Procedures

Automated Procedures for Validating Geolocation Accuracy Designed into Level 1A Geolocation Processing System (described above)

Additional Manual Validation will Verify Performance of Automated Methods and to Monitor and Measure Geometric Characteristics not Captured by Routine QA Processing

MCST Will Use SRCA for Band to Band Registration

Orbit to Orbit Registration will be Validated Using Manually Extracted Image to Image Tie Points

Frequency Dependent on Observed Performance of MODIS Instrument in Flight

Calibration Sites

Ground Control will be Derived from Existing Image, Map and Digital Cartographic Data Sources

Global Distribution of Ground Control Needed with a Few Orbital Paths Selected for Intense Coverage

No requirement for Newly Acquired Field Data is Anticipated

MODIS Geometric Calibration - Key Personnel

Senior Analyst Experienced in

- Sensor Geometric Modeling
- Satellite Photogrammetry
- Spatial Data Processing (especially digital elevation data)
- Statistical Analysis

Geolocation Risk Analysis

Specification Risks

- Allocation of Error Budget Between Static and Dynamic Sources is Not in Specification

Ancillary Data Risks

- DTM - Global Availability, Accuracy
- Ephemeris - Number and Length of TDRSS contacts
- Ground Control - Global Availability, Cost, Map Accuracy

Algorithm Risks

- Blunders
- On-line Optical Navigation (2 pass)
- Processing Time